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GRAVITY VENTILATION OF
PROTECTIVE SHELTERS

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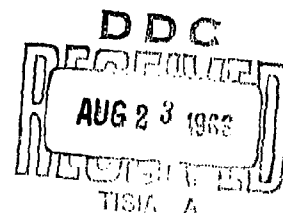
GRAVITY VENTILATION OF
PROTECTIVE SHELTERS

Y-F011-05-340

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by

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ABSTRACT

The obvious alternate to a power operated ventilation system for
a protective shelter is natural draft. The possibilities, limitations
and some alternates for simple augmentation of natural draft are out-
lined. These include the use of a flame in a flue, both with and
without thermoelectric power generation. A simple design procedure
and demonstration test program are outlined. The work was authorized
by Reference 1.

INTRODUCTION

The most critical commodity to the inhabitants of protective shelters is air. Conceivably, people could live through an extended period without food or water, and with little or no sanitation facilities of the class to which they are accustomed, but they must have air. The usual criteria on shelter ventilation systems produce rather elaborate blowers requiring power, and having a high pressure loss through filters. Because of the uncertainty in continuity in power generation, there is always the finite probability of failure, and a requirement for alternate ventilation, preferably by natural means. A protective shelter is basically and intrinsically disposed for the promotion of a certain flow due to gravity under heads imposed by differences in air density, a result of heat rejection by the occupants. This report proposes to consider the limitations of an emergency gravity system, the special problems it creates in shelter construction, and considers the possibility of augmentation of the natural draft by use of simple burners. There is no intention to suggest the avoidance of the installation of complete forced air systems for primary ventilation requirements under design operating conditions.

DESCRIPTION

In describing a possible system of the type contemplated for emergency ventilation of a protective shelter, it might be more appropriate to identify it as natural ventilation. There is frequently, if not usually, a positive draft head other than natural gravity to induce air movement into and from the shelter. Specifically, surface winds, when available, could be reliably used for augmentation of the other natural draft forming agent, the difference in local pressure due to difference in density caused by introducing heat into the ventilation air. In Figure 1, air enters at a temperature of, say 80°F through a duct A from the surface which need protrude vertically only sufficiently far to avoid the entry of surface water. The useful extension of the exhaust stack, B, above the surface can be any practical height dictated by location of the shelter, requirements for strength against blast, etc., but the taller, the better. It has been suggested that a telescoping chimney, cranked up after the blast, might be a practical method of

enhancing the draft after the arrival of the shock wave. In the
simplest application, heat from the (nominally 100) residents of a
shelter in the amount of about 225 Btu's per person per hour warms the
air. The air, now less dense than the incoming air, rises to the
exhaust duct at perhaps 95°F near the ceiling. The draft available
for circulation in the system is:

$$h_a = H (\rho_o - \rho_1), \text{ where:} \tag{1}$$

h_a is the head available, feet of fluid (air) flowing

H is the total vertical distance from the center of
the inlet of duct A to the top of the stack, B.

ρ_o and ρ_1 are the densities of the outside or
incoming and inside or heated air respectively.
Both values must be adjusted averages to correct
for heat transfer, temperature stratification, etc.,
in the actual situation.

The total friction in the system can be calculated by standard
methods, of which probably the best known is Fannings Formula:

$$h_f = C \frac{L V^2}{2g}, \text{ where:} \tag{2}$$

h_f is the friction head, feet of fluid,

V is the velocity, feet per second

L is the length of the ducting, feet

g is the acceleration due to gravity, feet per second per second

C is an experimental constant, varying with roughness and flow
rate, ft^{-1} .

In an operating system, equation (2) gives the obvious and generally
recognized loss in the system. In addition, with every entry (a contrac-
tion) into a duct and exit (expansion) there is a loss in local pressure
necessary to accelerate the fluid and a loss in kinetic energy, usually
equivalent to practically the entire velocity head upon abrupt expansion
into a large space.

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In addition to the above, the desired condition in the protective shelter designed for use in event of nuclear warfare would include at least a particulate filter, D, Figure 1, capable of removing radiation-bearing soil particles arising from interaction of a nuclear weapon with the earth. It is also frequently desired to provide protection against possible bacteriological and chemical warfare agents which required the use of additional filters. The filter agents are usually so-called absolute paper filters with exceedingly small pores and activated charcoal beds respectively, both of which have relatively high pressure drops as normally used. In a first appraisal, it appears that only a nominal 1" thick fibre impregnated filter medium can be accomodated under favorable conditions without mechanical draft.

One possible serious impediment to satisfactory functioning of the simplest of natural draft systems, in which heat to produce the circulating heat is supplied by the shelter occupants, will be the hand-cranked blowers usually specified for routine (in the case of family shelters) or emergency operation in larger shelters. Data supplied by one manufacturer indicates that their unit, designed for producing a 3/4" draft of static pressure at 202 cfm has a static pressure drop when not in operation of 3" of water at 200 cfm, approximately. Such a device, if used at say, 6 cfm per person for 5 people in a small home shelter, to which it apparently is well adapted, would have a static pressure drop when not operating of about 0.09 inches of water at 30 cfm. Even this small resistance will later be seen to be excessive for a gravity system. From this we may expect to have to remove any and all such restrictions during operation of a gravity system.

LIMITATIONS OF THE SYSTEM

By calculations of the type used in equations (1) and (2), it can be demonstrated that minimum ventilation requirements can be furnished by a gravity ventilation system in a variety of sizes and types of shelters, provided no large restrictions in the form of hand blowers, dense filters, etc., are placed in the system. See Figure 2. Very careful but straightforward duct design will be desirable and usually necessary. Using body heat of occupants, it can be seen from heat release information such as that of Figure 3 (ASHRAE 1960 Guide, Chapter 6, Figure 6),[4] that body heat will fail to produce a draft as the ambient temperature ascends. For 75°F, approximately 300 Btu's per person is available; at 90°F, body heat is rejected largely as latent heat and only about 50 Btu's per hour per person would be available as sensible heat for producing natural draft in the shelter. Some of this heat would be absorbed by the shelter walls. Considering heat loss from the shelter to soil, the gravity system will be seen to

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have failed with just this moderate increase in ambient temperature
of the air. To insure functioning of a gravity system under unfavor-
able conditions, auxiliary draft will probably have to be provided.
The most obvious avenue for augmentation of draft under unfavorable
climatic conditions is to use a flame in the exhaust or chimney duct.
An adequate design will probably require higher ventilation velocities
than the first example, in order that the occupants will be bathed in
incoming air at something like the outside dry bulb temperature, and
not be oppressed by their body heat and moisture. The importance and
scalar value of such air volume increase will depend upon the ability
to secure vertical air motion; in a 12' high shelter it may, for instance,
be possible to secure such complete stratification of warm air and body
reject odors, CO_2, etc., that the minimum air supply required (taken
here arbitrarily[2] as 6 cfm, which is 1-1/2 times that necessary to keep
the CO_2 to 0.6%, and many times the minimum requirement for oxygen
depletion),[7,8] may be decreased.

A first calculation for 27 cfm for a home-size shelter indicates
that about 10 gallons of kerosene (or an equivalent heat input of
propane, etc.) will produce a draft for 2 weeks. No credit is taken
for body heat in this example, which is detailed in Figure 2. The
point of operation of such a system is illustrated as the intersection
of 2 curves; this particular curve is only approximate and will require
experimental correction or verification. Establishing a very tenta-
tive rule of thumb, we may expect that something of the order of
2-1/2 gallons of petroleum fuel burned correctly would supply the
ventilation for 1 person for 2 weeks. With proper periodic adjustment
of burning to take advantage of low ambient temperatures, etc., this
might be reduced.

It is instructive to consider alternate methods of supplementing
the draft produced by a flame in a simple system such as is contemplated
in Figure 2 and schematically shown in Figure 4. With the advent of
increasingly better semi-conductor materials for direct conversion of
thermal energy to direct current electricity by use of thermopiles, it
may be expedient to use the more reliable if less efficient piles
directly in the flame; the power would be used for producing minimum
illumination and/or augmented draft, using a small blower.

As an example, consider the design point of operation of 27 cfm
in Figure 2.

The useful horsepower produced is:

$$HP = QWH/33,000 =$$

$$= \frac{(27)(0.0734)(0.03)(75*)}{33,000} = 1.35 \times 10^{-4} \ HP \qquad (3)$$

*In this substitution, the total head is obtained
by multiplying the head, inches of water (0.03)
by a conversion factor to feet of air of 75, and
approximate value for air of a density of 0.07 pcf

With such low total horsepower of real interest, we may hypothesize
that even very inefficient conversion and application of thermal energy
by thermocouples, etc., may be useful. The approximate thermal input
in horsepower, using 10 gallons of kerosene in 2 weeks is:

$$HP \text{ equivalent of heat} = \frac{(Btu/\#) \ (\#/gallon) \ (gallon)}{(hours) \ (Btu/Hp \ hr)} \qquad (4)$$

$$= \frac{(19,810)(6.82)(10)}{(14)(24)(2545)} = 1.58 \ HP \qquad (4a)$$

Here, the 100% conversion of the relatively small quantity of
fuel would produce sizeable horsepower, and the requirements for a
system which would produce an additional power equivalent of, say, 5
times that accomplished by the simple gravity augmentation of Figure 4,
would be:

$$Eff \ Required = \frac{(Required \ Factor, \ Dimensionless)(Gravity \ HP)(100)}{(Potential \ HP \ at \ 100\% \ conversion \ Eff'y)} \qquad (5)$$

$$= \frac{(5) \ (1.35 \times 10^{-4}) \ (10^2)}{1.5} = 0.045\% \qquad (5a)$$

An efficiency of 0.045% would, for most practical engineering
applications, be of little if any interest. Here, it appears that even
considering low efficiencies of the order of 10% in fan-motor combina-
tions, the necessary efficiency of conversion would be of the order of
only about 0.5%, well within the capabilities of currently available

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thermo-electric direct conversion[5]. On a linear basis, person-to-person, power for a 100-person shelter would be of the order of 3.4×10^{-3} HP. The rest of the arguments would hold except that a better application could be expected to be found in the larger installation, with probably higher efficiencies in equipment and higher overheads in the shelter to enhance stratification of warm air near the roof.

ENHANCEMENT OF STRATIFICATION

It was suggested above that lesser quantities of air would be acceptable if stratification and air flow vertically could be assured. A gravity system designed to systematically distribute air at many points near the floor, collect it at many points near the ceiling would probably not be successful because of the high duct losses that would be encountered. However, it is entirely possible by use of a minimum of false floors, propitious arrangements of equipment, cabinets, partitions, etc., that vertical flow could be materially aided over that which would be found in the simplest arrangement as shown in Figure 1. Where body heat of personnel is to be utilized to the fullest, any partitions around individuals will obviously benefit the situation. Vertical overhead 'egg crate' diffusers of the lightest construction should assist. In any event, the ventilation requirements as outlined in references 6 and 7 for circulation and temperatures should be held insofar as is possible.

EXPERIMENTAL PROGRAM

An experimental program would include perhaps 2 shelter sizes of the types discussed above and shown in the figures. The designs as tested should be based on the complete requirements of the shelter concept, including the requirements for introducing the ducts at a point which will not compromise the radiation protection afforded[8]. This particular concept requires that penetrations enter outside the zone indicated in Figure 5, taken from the reference, or that they be sufficiently tortuous that radiation cannot stream freely along their length.

CONCLUSIONS

It is concluded that:

(1) Subject to the limitations imposed by high ambient temperatures,

minimum shelter ventilation during periods of emergency operation when electric power is not available can be accomplished by utilization of body heat by shelter occupants.

(2) During critical periods of high ambient temperatures, shelter temperatures and body heat rejection will be such that gravity ventilation must be augmented by other devices; a system utilizing a flame in the exhaust chimney is described.

(3) Systems such as suggested in (2) above may be readily augmented by use of thermo-electric conversion at very low efficiencies, well below those available in currently available devices.

(4) A gravity system will be enhanced in usefulness if vertical flow of air upward can be secured by any means, and temperature and vapor stratification insured.
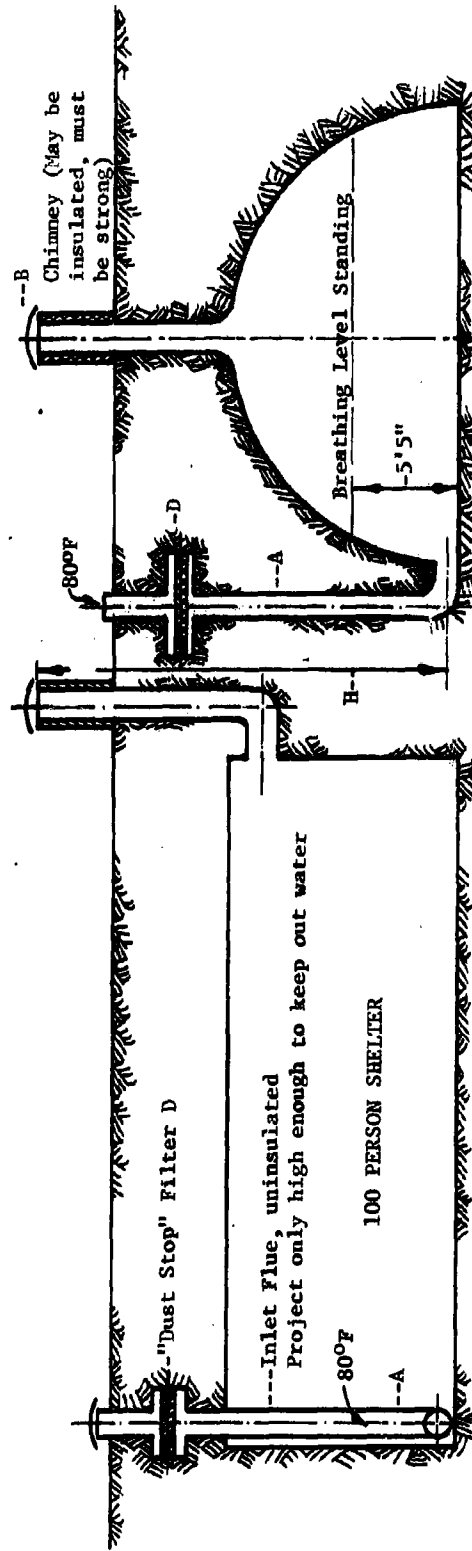

FUTURE PLANS

Experiments being prepared will be based upon the philosophy and tentative designs suggested in the report text and conclusions.

REFERENCES:

1. BUDOCKS Task Instruction to NCEL Task Y-FO11-05-340, "Gravity Ventilation of Protective Structures," 15 March 1962.

2. KONZO, S. "Winter Air Conditioning," National Warm Air Heating and Air Conditioning System and Engineering Experiment Station, University of Illinois, 1939.

3. "Mechanical Engineers' Handbook," Ed. L. S. Marks, 4th Edn. P1186.

4. "Guide," 196, Ame. Society Heating Refrigeration and Air Conditioning, (p 159, 1960 Guide) & Chapter 36, p 531.

5. "Potential of Thermoelectric Devices in BUDOCKS Applications," NCEL Technical Report R-142 of 13 April 1961.

6. "Shelter Habitability Studies - The Effects of Oxygen Depletion and Fire Gases on Occupants of Shelters," NCEL Technical Report R-144 of July 1961.

7. "Shelter Habitability Studies - Odors and Requirements for Ventilation," NCEL Technical Report R-146 of May 1961.

8. "Analysis of the Critical Shielding Volume for Underground Shelters," NCEL Technical Note N-381 of February 1960.

Figure 1

$T_a = 80°F$

Chimney (May be insulated, must be strong)

--B

Breathing Level Standing

5'5"

80°F

--D

--A

H

"Dust Stop" Filter D

Inlet Flue, uninsulated
Project only high enough to keep out water

80°F

--A

100 PERSON SHELTER

Design Example: 100 Persons
6cfm/person (minimum)
Filtering, 1" Dust Stop, no absolute filter
Duct Diameters, 12", round, smooth metal
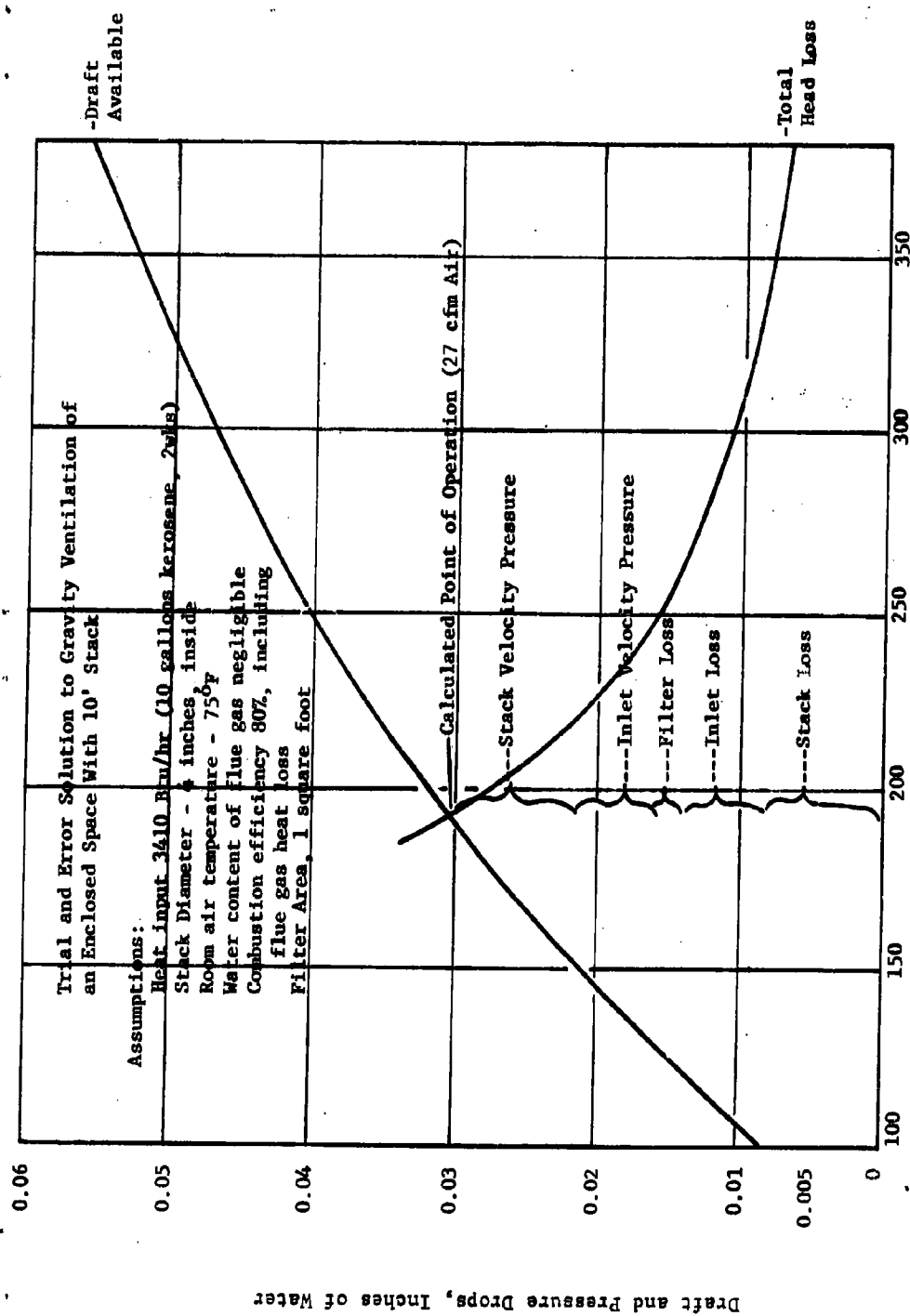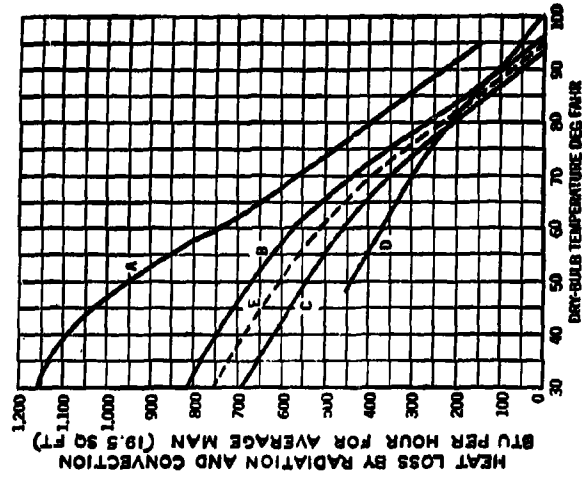Duct Lengths: Inlet, 18'
                Outlet, 10'

Trial and Error Solution to Gravity Ventilation of
an Enclosed Space With 10' Stack

Assumptions:

Heat input 3410 Btu/hr (10 gallons kerosene, 2 wks)
Stack Diameter - 4 inches, inside
Room air temperature - 75°F
Water content of flue gas negligible
Combustion efficiency 80%, including
    flue gas heat loss
Filter Area, 1 square foot

-Draft Available

-Total Head Loss

-Calculated Point of Operation (27 cfm Air)

--Stack Velocity Pressure

---Inlet Velocity Pressure
---Filter Loss
---Inlet Loss
---Stack Loss

Draft and Pressure Drops, Inches of Water

Average Stack Temperature, F
Room Temperature, 75°F
10 Foot Stack

Figure 2

Figure 4. Schematic of Flame Augmented
Gravity Chimney

From ASHRAE Guide 1960. Used with permission

Figure 3. Typical Body Heat Loss as a Function
of Ambient Temperature

RECTANGULAR SHELTER

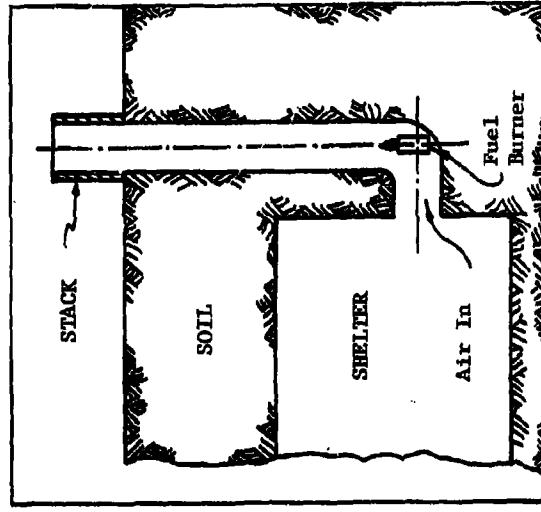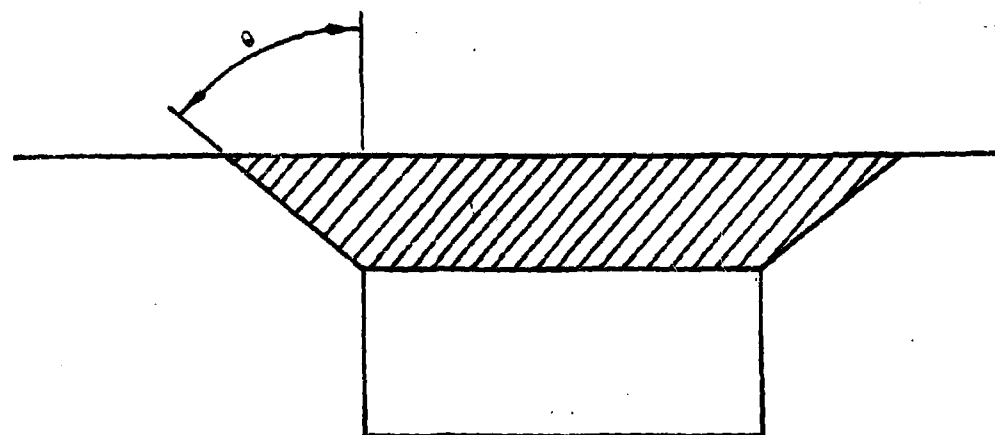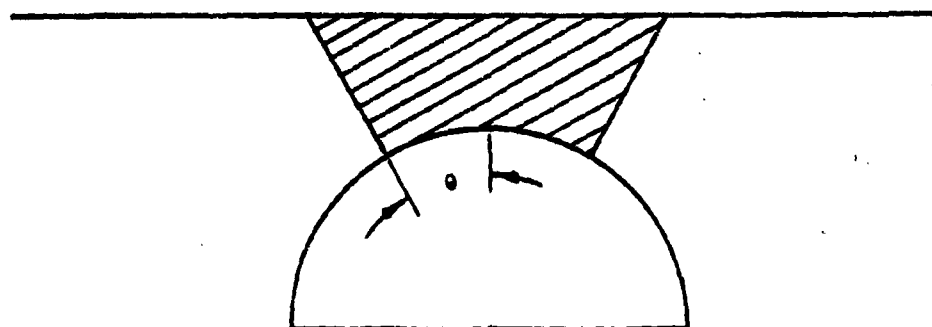HEMISPHERICAL SHELTER

Figure 5: Critical Shielding Volume for Rectangular and
Hemispherical Shelters